Valley
POWER SYSTEMS, INC.

AUTHORIZED DISTRIBUTOR
ELECTRO MOTIVE

NEW 144-AUTO FERRIES PROJECT
4420 14TH AVENUE NW – SEATTLE, WA 98107 Tel. 206-834-2329 Fax. 206-782-5455

1-DOC-002 Rev. -
(Formerly Calculation P-0291-02)

Contract 00-6679

ENGINEERING CALCULATION

LAYOVER HEATING SYSTEM HEAT REQUIREMENTS & HEAT EXCHANGER SIZING

Calculation of allowable volume of Vessel Coolant System external to engine skid-mounted package inclusive of both Main Coolant and SCAC Coolant Systems that is accommodated by EMD Standard coolant expansion tank.

3/30/06

CHRISTOPHER K. LANE
STATE OF WASHINGTON
41575
REGISTERED
PROFESSIONAL ENGINEER

EXPIRES 9/30/07

Performed by: ____________

Date: 3/30/2006

CALCULATION

TITLE: LAYOVER HEATING SYSTEM HEAT REQUIREMENTS AND HEAT EXCHANGER SIZING

PURPOSE:

Determine the adequacy of the "preferred" Layover Heat Exchanger which is common to the Jumbo Mark II Class, and estimate the requirements for Vessel supplied heat to maintain the engine at or above the specified temperature during Layover.

SPECIFICATIONS:

Specifications: At 5.2.3 (m) - *Engine Layover Heat System, tapping off the heat recovery loop, including factory modifications to the engine and pump with motor (480VAC, 3 phase, 60Hz), heat exchanger, and controls. The lay-over heat system shall be designed such that the system temperature does not drop below 140F degrees.*

The specifications do not detail the limiting conditions where this minimum Layover temperature must be maintained, so assumptions are made based on reasoning as discussed below.

DISCUSSION AND ASSUMPTIONS:

We are not aware of the existence of an engineering calculation for the heat losses from any EMD engine, 12-cylinder or other size, nor of any detailed empirical data, but it is well established that the standard 15 kilowatt electric heater often provided by EMD, operating in cycling duty, maintains engine temperatures of 130 F or more in EMD engines up to 20-cylinders in size. We also understand that the Layover Heating Systems in the Jumbo Mark II vessels equipped with the same model Heat Exchanger and Circulating Pump as is assumed in this case operate "satisfactorily" on those larger 16-cylinder EMD's, though we lack specifics.

Suffice to say that it might be "reasonable" to simply assume that providing the equivalent of 15 kW of heat to this layover System would be sufficient, and that if the Jumbo Mark II systems are "satisfactory" the same equipment would surely work on the smaller 130-Auto class 12-cylinder engines, a verification calculation will be performed.

This verification calculation will use a simplified, but conservative, convective + radiant[1] heat loss method based on a conservative estimate of the heated equipment surface area for a range of possible Engine Room ambient temperatures from 70°F to down to 35°F. The critical parameters in this calculation, other than the obvious factor of surface area, is the Heat Loss Coefficient (U), which has been derived from published literature by the Watlow Company, a well known heater manufacturer.

[1] Black Body radiation is assumed in the curves as it is the "worst case".

REFERENCES:

1. Valley Coolant Schematic Drawing 1-77270-033
2. http://www.watlow.com/images/reference/refdata/0303bal.gif & /0303.cfm (attached)
3. Valley General Arrangement Drawing 1-77270-001
4. Young-Touchstone Heat Exchanger Data Sheet Model F 502-DY-4P

CALCULATION:

Heat Loss Coefficient (U): (Reference 2)

The Heat Loss Coefficient (U) is a measure of the rate of energy loss from the equipment to the Engine Room ambient air. This coefficient is in units of Watts/in^2. Reference 2 provides curves for this coefficient as it would apply to a bare, uninsulated metal surface both with and without consideration of "Black Body" radiation effects. Because painted steel has emissivity, that is the propensity to "radiate" heat, that is a very small fraction (10% or less) of an ideal black body, and because paint as exists on EMD engines is a reasonably good insulator compared to bare metal, the Heat Loss Coefficient (U) from this graph would be from the very lower-left extreme at about 0.1 Watt/ in^2. That is:

$U_{140/70} = 0.1$ Watt/ in^2 (referenced to 140F steel in 70F air)

Surface Area of Heated Equipment: (see Reference 3)

Reference 3 is the General Arrangement drawing for the Main Engines. From inspection of this drawing and with a general though certainly subjective understanding of the convolutions in the surfaces involved, it is thought reasonable to approximate the total "effective" surface area of the heated equipment, principally the engine itself, by calculating the surface of a rectangular box that would enclose the engine (like a shipping container) and multiplying that value by 1.2.

Possibly it is helpful to think of just such a box made of a plastic film that could be heated and would form to the surfaces much like "shrink-wrap", except that in this case the plastic does not shrink in surface area but does form around the engine much like shrink-wrap.[2] It is believed that such a box would have *almost* enough material to cover all the engine surfaces, and that the additional 20% would fill the shortage and compensate for heat that escapes by conduction to connected equipment such as through fluids and piping to the unheated accessories.

The dimensions for the box proposed by this logic is estimated as:

Length = 15 ft.
Height = 10 ft.
Depth = 5 ft.

[2] If the term "Shrink-Wrap" is in any way a protected trade name that should appear in some other form or with trademark annotations, my apologies!

The surface area of this box (A) would then calculate as:

$$A_{box} = 2\ (15 \times 10) + 2\ (15 \times 5) + 2\ (10 \times 5) = 550\ ft^2.$$

Assuming that the total area of the equipment A_{Tot} is 1.2-times the area of the box, then;

$$A_{Tot} = 1.2 \times A_{box} = 1.2 \times 550\ ft^2 = 660\ ft^2 = 95{,}000\ in^2.$$

Total Heat Losses from Equipment (Q) at Reference Conditions 140°F to 70°F:

The rate of heat loss from the equipment (Q) is the product of the Heat Loss Coefficient and the Total Area. Using subscripts that indicate both the equipment temperature (T_1) and the ambient temperature (T_a), the following results are obtained for our reference conditions of 140°F equipment temperature and 70°F ambient temperature.

Therefore generally:

$$Q_{T1/Ta} = U_{T1/Ta} \times A$$

And for our reference case:

$$Q_{140/70} = 0.1\ W/\ in^2 \times 95{,}000\ in^2 = 9{,}500\ \text{Watts}\ (10\ kW)$$

Because heat transfer generally is proportional to the temperature differential, we can apply this result to other ambient temperatures by ratios of the temperature times the reference result as follows:

$$Q_{140/60} = Q_{140/70} \times (140\text{-}60)/(140\text{-}70) = 9{,}500 \times 80/70 = 10{,}860\ \text{Watts}\ (11\ kW)$$

$$Q_{140/50} = Q_{140/70} \times (140\text{-}50)/(140\text{-}70) = 9{,}500 \times 90/70 = 12{,}214\ \text{Watts}\ (12\ kW)$$

$$Q_{140/40} = Q_{140/70} \times (140\text{-}40)/(140\text{-}70) = 9{,}500 \times 100/70 = 13{,}571\ \text{Watts}\ (14\ kW)$$

$$Q_{140/35} = Q_{140/70} \times (140\text{-}35)/(140\text{-}70) = 9{,}500 \times 105/70 = 14{,}250\ \text{Watts}\ (14\ kW)$$

Adjustment for Possible Increases in Heat Loss Coefficients:

The calculation above is based on a Heat Loss Coefficient U = 0.1 Watt/in^2. Inspection of the references suggests this is likely to be the correct coefficient but that it is not obviously conservative. Engineering judgment suggests that the coefficient could be somewhat higher particularly if the Engine Room ventilation induces a cooling effect. As such, the following table of results is provided and the more conservative results used in development of design heat loads and other design criteria:

	U = 0.1 W/in^2	U = 0.12 W/in^2	U = 0.15 W/in^2
$Q_{140/60}$ =	10.9 kW	13.1 kW	16.4 kW
$Q_{140/50}$ =	12.3 kW	14.8 kW	18.5 kW
$Q_{140/40}$ =	13.6 kW	16.3 kW	20.4 kW

$Q_{140/35}$ =	14.3 kW	17.3 kW	21.5 kW

Based on this data, a Design Parameter of 21.5 kW would cover all cases with substantial conservatism and would, absent other constraints that could include economics, be the recommended design value for the vessel heat load.

Heat Exchanger Capacity:

Reference 4 (attached) is the data sheet for the Layover Heat Exchanger model that is currently in use on the Jumbo Mark II vessels. This data sheet is referenced to a engine-side return temperature of 100°F, not 140°F as applies to this project, but the data is applicable for determining total design capacity and the data indicates that this model exchanger can be used to temperatures up to 350°F.

The design "Heat Load", or heat capacity (Q) of this unit is indicated as "2176 BTU/Min"; that is:

$$Q_{HX} = 2176 \text{ Btu/Min}$$

Since 1 KW = 3,413 Btu/Hr., this converts to:

$$Q_{HX} = (2176 \text{ Btu/Min}) \times (60 \text{ Min/Hr}) / (3413 \text{ Btu/Hr.}) = 38.25 \text{ kW}$$

That is, the heat transfer capacity of this heat exchanger is about 38 kW as compared to the 15 kW for a standard EMD electric immersion heater and as compared to the range of 12 to 15 kW calculated above for heat loss from the engine at various ambient temperatures. That means that this heat exchanger has over twice the heat transfer capacity required for this project, with the only downside being that it may be just a bit larger and heavier then necessary, but is considered "a good fit".

Translation of Design heat Load to Vessel-Side Flow and Temperature Requirements:

Flow Rate – Recommended Range:

The selected Heat exchanger is designed for a flow rate of 15 GPM on the Vessel-side of as indicated in Reference 4, but that would be considered a nominal "maximum" since the duty required of the heat exchanger of 21.5 kW calculated above is significantly less than the heat exchanger design capacity of 38.25 kW. Therefore:

$$Flow_{max} = 15 \text{ GPM}$$

On the other hand, the heat exchanger design being based on a Vessel-side differential temperature of 17.7° F suggests that a minimum flow rate for delivery of the design heat rate of 21.5 kW would call for a minimum flow rate on the Vessel side calculated as:

$Flow_{min}$ = 15 GPM x (21.5 kW/38.25 kW) = 15 GPM x (0.56) = 8.5 GPM

Based on this and with addition of just a bit more margin the recommended range of flow to be supplied by the Vessel would be:

Recommended Flow Rate = 10 GPM to 15 GPM with the higher flow rate preferred so as to minimize the peak temperature required of the Vessel-side heating loop as detailed below.

Temperature Requirements:

The specified engine layover temperature of 140 F is relatively "high" for a non-electric heating applications. As such, even at the maximum Vessel-side flow rate of 15 GPM, the Vessel-side heating loop inlet temperature to the Layover Heat Exchanger is correspondingly "high". Using the heat exchanger design temperature differentials adjusted for required duty of 21.5 kW provides the following results assuming 15 GPM on the Vessel-side loop and based on keeping a low side differential temperature between Engine and Vessel loops of 10 F (not as much as HX design value of 122.3 – 110.5 = 11.8F but know as not being needed at the lower duty):

Engine Side:
Inlet Temperature = 140 F (minimum per spec.)
Outlet Temperature = 140 F + (10.5 F x 21.5/38.25) = 146 F

Vessel-Side:
Inlet Temperature = 150F + [(21.5/38.25) x (140F-122.3F)] = 160 F
Outlet Temperature = (140F + 10F) = 150 F

Temperature and Flow requirements of Vessel-side Heating Loop:

If Vessel-side flow were reduced from the maximum of 15 GPM to the minimum (nom.) of 10 GPM, the range of possibilities are as detailed in the following table:

Vessel-side Flow	Inlet Temperature	Outlet Temperature
15 GPM	160 F	150 F
12 GPM	162.5 F	150 F
10 GPM	165 F	150 F